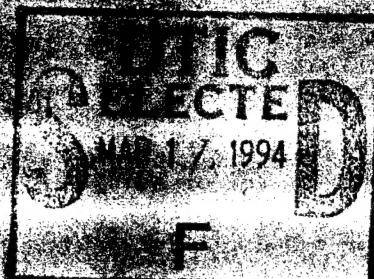


GAO

Report to the Honorable
Brock Adams, U.S. Senator

GAO-94-591

NUCLEAR SCIENCE



Accelerator Technology for Plutonium Production Needs Further Study



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Resources, Community, and
Economic Development Division

B-231142

October 31, 1991

The Honorable Brock Adams
United States Senate

Dear Senator Adams:

In your February 7, 1990, letter you expressed concern about whether the Department of Energy (DOE) has given full and fair consideration to using a particle accelerator for tritium production. You specifically requested that we review an assessment made by DOE's Energy Research Advisory Board (ERAB) and its resulting February 1990 report on the feasibility of using an accelerator to produce tritium. You asked that we (1) determine the appropriateness of the criteria used by ERAB in performing its assessment and (2) evaluate the cost estimates used in the ERAB report. In addition, we are providing you with information on recent developments that have important implications for developing the accelerator technology.

DOE has historically produced tritium in nuclear reactors located at its Savannah River Site. However, particle accelerators have recently surfaced as a potential technology for tritium production. This technology involves accelerating protons at nearly the speed of light and crashing them into lead, which would create neutrons. The neutrons would be used to produce tritium in much the same way that they are used in a reactor.

In February 1990 we issued a report on the technical feasibility of accelerator production of tritium.¹ The report concluded that while the technology does have uncertainties that need engineering development, accelerator production of tritium appears technically feasible. In addition, we noted that the accelerator presents fewer safety and environmental concerns than tritium production using a reactor. Our report also noted, however, that a major disadvantage of a large single accelerator capable of producing 100 percent of the 1988 tritium need—a requirement established by DOE—is the large amount of electrical power required for its operation. Such an accelerator would require about 900 megawatts of electricity, or the equivalent of a large generating facility. As a result, we included information in our report on the implications of building smaller-sized accelerators that would produce less

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¹Nuclear Science: The Feasibility of Using a Particle Accelerator to Produce Tritium (GAO/RCED-90-73BR, Feb. 2, 1990).

tritium, use less electricity, and maintain their safety and environmental advantages. Such accelerators could be very flexible in meeting changes in the demand for tritium.

Results in Brief

The ERAB report did not provide a complete assessment of the accelerator technology for tritium production. In this respect, the criteria used by ERAB limited the scope of its assessment to a large accelerator capable of producing 100 percent of the 1988 tritium need. Such an accelerator would require a large amount of electric power. The electric power requirement could be a disadvantage because it could require the construction of a new generating facility—one able to generate about 900 megawatts. Smaller accelerators capable of producing 50 percent or 25 percent of the needed tritium were not considered by ERAB. Smaller accelerators, each using less electric power, could be located in different geographical areas where excess power is available, thus possibly alleviating the need for new power-generating facilities. Smaller accelerators could be deployed to provide more flexibility in meeting changes in the demand for tritium.

Cost estimates for accelerators to produce tritium are very uncertain because a detailed design has not been done. Further study is necessary to develop meaningful cost estimates. The cost estimates for the accelerator technology contained in the ERAB report were significantly higher than estimates previously reported by Grumman Aerospace Corporation, Los Alamos National Laboratory (LANL),² and GAO. The reasons for this difference include higher ERAB cost estimates for (1) contingencies to cover the risk in building the entire accelerator structure and (2) annual operating cost. These higher estimates may not be appropriate in view of the generally low risk associated with most of the major accelerator components and the operating experience gained from existing accelerators.

Recent developments could increase the potential benefits of developing the accelerator technology. Decreases in the projected future need for tritium to service existing and planned nuclear weapons may make the use of a small accelerator for tritium production more attractive. For example, if the 1988 tritium need is reduced by 50 percent, then an accelerator approximately one-half the size of that assessed by ERAB could be used to produce the needed tritium. This would result in nearly

²These estimates were contained in a joint report by LANL and Brookhaven National Laboratory entitled Accelerator Production of Tritium (APT), Mar. 1989.

proportional capital cost savings and significantly lower operating costs. Another recent development is a new tritium target concept proposed by scientists at LANL for accelerator production of tritium. It has a potential for overall cost savings and would reduce radioactive waste from the tritium production cycle. The concept's practical use, however, needs to be further studied.

Although the use of accelerators for tritium production has potential benefits over reactor technologies, these benefits must be weighed against the maturity of the technology and uncertain cost. While we take no position on constructing an accelerator for production of tritium, we do believe the technology deserves more balanced consideration in DOE's tritium production planning. In particular, the utilization of smaller accelerators may offer advantages over a large accelerator in terms of cost and flexibility.

Background

Tritium is a radioactive material used in nuclear weapons that, because of its relatively rapid rate of decay, has to be periodically replenished to maintain the effectiveness of the weapons. DOE is responsible for producing tritium and historically has done so using nuclear reactors. However, the reactors used in the past have experienced aging and safety problems and have been shut down since 1988 for repairs. Because of future uncertainties in the use of these reactors, ERAB, at the request of DOE, in 1988 assessed various reactor technologies for tritium production. As a result, DOE began to pursue a program to design and construct two new tritium production reactors. However, in February 1991 the Secretary of Energy stated that only one reactor would initially be constructed because of budget constraints. DOE plans to announce the selection of the reactor technology and the location in December 1991.

As part of ERAB's 1988 assessment for new tritium production technologies, particle accelerators were briefly assessed and determined not to be sufficiently developed for further consideration by ERAB. However, in February 1990, ERAB issued a report that concluded that the technology was technically sound and had safety and environmental advantages over reactors. (See app. I for more detailed background information.)

Scope of ERAB Assessment Limited

DOE asked ERAB to evaluate accelerator technology using the same criteria, whenever possible, that it applied to its 1988 assessment of reactor technologies for tritium production. Accordingly, one of the major criteria used by ERAB was that the accelerator technology be

capable of annually producing 100 percent of the tritium need as established by DOE in 1988. This was the same criterion used in ERAB's 1988 assessment of reactor technologies. This criterion limited the ERAB assessment to a large or full-size accelerator³ that would require a large amount of electric power to operate. ERAB did not assess smaller accelerators that would produce smaller amounts of tritium.

The ERAB assessment and resulting report noted that a major disadvantage of a large or full-size accelerator for tritium production was acquiring and ensuring the continued large supply of electric power. The power required to operate a full-size accelerator was estimated at 900 megawatts by ERAB, or the equivalent of a new power plant. On this basis, ERAB concluded that if a new power plant was required, most of the advantages of the accelerator would be lost because any environmental impact assessment would have to include the impact of a new power plant. Although ERAB did not assess smaller accelerators that would use less power and provide more flexibility in acquiring and ensuring the necessary power, it did note that if the need for tritium was reduced, the accelerator cost would decrease significantly. (See app. II for more detailed discussion of ERAB's assessment.)

Our February 1990 report on accelerator production of tritium included a detailed discussion of smaller accelerators and how they would lessen the impact on power requirements. According to LANL officials, the power requirement for an accelerator capable of producing 50 percent of the 1988 tritium need is 465 megawatts and 260 megawatts for an accelerator capable of producing 25 percent of that need. While these amounts of power are significant, they may not require a new power plant. In this respect, the smaller the amount of electric power required, the more flexibility DOE has in acquiring the necessary power. Smaller accelerators could be sited in different areas of the country where excess power is available. In our February 1990 report, we included discussions of smaller accelerators as one possible option in meeting our future tritium needs, because DOE had previously considered various combinations of smaller reactors during its 1988 assessment of reactor technologies for tritium production.

³The full-size accelerator assessed by ERAB is one capable of producing the amount of tritium necessary to support the nuclear weapons program, as established by DOE in 1988.

ERAB's Cost Estimates Higher Than Previously Reported

DOE and its contractor, Martin Marietta at Oak Ridge, Tennessee, initially developed the ERAB estimates using cost estimates prepared by LANL and an independent cost study prepared by Grumman Aerospace Corporation.⁴ DOE/Martin Marietta substantially increased the cost from these estimates primarily because of risk and uncertainties. ERAB, in turn, slightly modified the DOE/Martin Marietta estimates before publishing them in its final report. These final estimates were not independently verified by an organization distinct from ERAB such as DOE's independent cost estimators. According to DOE officials, the highly speculative nature of the cost estimates and the preliminary nature of the system design did not justify an independent verification of the costs. Moreover, in presenting the estimates, the ERAB report stated that the estimates were highly speculative.

Because of the lack of a detailed design for a full-size accelerator, we agree that it is difficult to develop an accurate estimate. Nevertheless, the ERAB estimate of capital cost as well as operating cost is substantially higher than the previous estimates by Grumman Aerospace Corporation or LANL. They are also higher than the estimates contained in our report on accelerators. The higher estimates contained in the ERAB report are primarily the result of increases in the (1) cost contingency assigned to the estimate for building the accelerator system and (2) operating cost for accelerators.

The total estimated capital cost contained in the ERAB report was \$5.3 billion.⁵ A major portion of this cost was a \$1.1-billion capital cost risk contingency used by DOE/Martin Marietta. In cost estimating, risk contingencies are routinely assigned to cost items because of perceived technical and schedule uncertainties. In this respect, DOE/Martin Marietta assigned a high risk to the cost of the entire accelerator structure because of technology and scheduling risks. In this regard, there was no firm conceptual design for the accelerator. However, it is important to note that the major components of the accelerator's structure, which make up about 72 percent of the accelerator's cost, have been manufactured and used in other accelerators. In addition, an ERAB technical assessment group determined that most of the major accelerator components were technically at low risk. Accordingly, such a high contingency cost may not be warranted.

⁴Unless otherwise noted, all cost estimates included in this report are in 1989 dollars.

⁵DOE/Martin Marietta's estimate formed the basis for ERAB's conclusion that a large accelerator system could cost from \$4.5 billion to \$7.0 billion.

The ERAB report estimates the operating cost for a large or full-scale accelerator to be \$800 million annually. The electric power costs for the accelerator account for a substantial portion of the total operating costs. The ERAB report stated that at DOE sites that could be used, the cost of electricity would exceed 50 mills/kilowatt hour (Kwh). The ERAB report uses 56 mills/Kwh in developing its operating cost estimate, which was DOE/Martin Marietta's estimated power cost for the year 2010 in the Pacific Northwest. In our view, actual power cost could be much lower. In this respect, the Bonneville Power Administration projects a "new resource customer" rate of 33.8 mills/Kwh in the Pacific Northwest for the year 2010. This cost is similar to the cost contained in our February 1990 report.

Finally, the ERAB report includes an estimate of \$140 million annually for capital upgrades. However, DOE/Martin Marietta officials who initially developed this estimate could not explain what capital upgrades would be necessary. According to these officials, this cost was added because similar costs had been added to the reactor costs that were assessed in 1988. DOE officials also told us that an annual capital upgrades cost of 3 percent of the capital cost is necessary to maintain a production system. In our view, this may be inappropriate for an accelerator. For example, LANL officials who operate the Los Alamos Meson Physics Facility—a large linear accelerator—told us that only general maintenance was required annually, with replacement of minor parts being required periodically. According to information acquired from LANL, the entire operating cost for this facility in 1989 was only \$17.8 million. Furthermore, replacement of one of the most costly components on the tritium production accelerator, the klystron tubes, was already included as a separate line item in the DOE/Martin Marietta cost estimates for the ERAB report. (See app. III for a more detailed discussion of ERAB cost estimate.)

Recent Events Affecting Accelerator Production of Tritium

Two recent events have added impetus to further study of accelerator technology. They are

- the projected decreased need for tritium to service existing and planned nuclear weapons and
- a new accelerator target concept, using helium-3.

Decreased Tritium Need

Our February 1991 report⁶ concluded that projected decreases in the amount of tritium needed to service existing and planned nuclear weapons raise issues about the best approach to building adequate capacity for tritium production. The report also points out that other production alternatives that DOE dismissed in 1988 may be worthy of further consideration.

Our February 1990 report on accelerator production of tritium noted that smaller accelerators—those capable of producing 50 or 25 percent of the 1988 tritium requirement as set by DOE—offer advantages over a full-size accelerator. The smaller accelerators would use less electricity, could be located in different areas, and could be readily upgraded for increased tritium production. In addition, any scale-down from full size would result in near-proportional decreases in capital and lower individual operating costs. The ERAB report also noted that if the need for tritium was reduced, the accelerator cost would decrease.

As a result of the projected reduction in the need for tritium, as discussed in our February 1990 report, a smaller accelerator than the ones assessed in the ERAB report may be capable of producing enough tritium to service future nuclear weapons. Further reductions in our nuclear weapons stockpile, such as those proposed by the President on September 27, 1991, could result in a substantially lower demand for tritium and further enhance the attractiveness of the accelerator concept.

Helium-3 Target Concept

The February 1990 ERAB report noted that the highest risk system associated with accelerator production of tritium was the proposed target. The proposed target was a configuration of tubes filled with aluminum-clad lead and lithium rods situated in a large vessel. The target was conceptual, and little if any empirical data existed concerning its feasibility.

Following the ERAB report, LANL looked for ways to improve the target technology. As a result, LANL proposed a target concept that would recycle decayed tritium (helium-3) back into tritium. The tritium used in nuclear weapons decays to helium-3 and eventually has to be replaced with additional tritium for the weapons to remain effective. The LANL process would separate the tritium that had not decayed from the

⁶Nuclear Materials: Decreasing Tritium Requirements and Their Effect on DOE Programs (GAO/RCED-91-100, Feb. 8, 1991).

helium-3 and then bombard the helium-3 with neutrons to produce tritium.

This target system is only a concept. Yet, it is a concept that has some very attractive features. The potential advantages of this conceptual system are that no target fabrication or tritium extraction facilities would be necessary and little radioactive waste would be created. Also, some limited experience in making tritium from helium-3 has been obtained at LANL. Furthermore, the process needed to separate the helium-3 from tritium has operated successfully for over 5 years at LANL as part of fusion reactor research. Finally, DOE has been separating and storing helium-3 from its nuclear weapons and has built up a substantial inventory. This inventory could be used to produce additional tritium by the above process if needed.

DOE officials questioned whether the helium-3 target is a practical engineering approach to producing tritium. They believe that there are numerous unknowns, such as the system's efficiency and how materials will react under neutron bombardment, that complicate the assessment of this target design. LANL officials, on the other hand, told us they have studied the performance and safety aspects of this system and believe it is not only technically feasible but also has a lower technical risk than the lithium-lead target initially proposed. We have been requested to examine in more detail the technical feasibility of this concept.

Conclusions

The criteria used to assess the accelerator technology did not provide the flexibility necessary to assess and report on the advantages of relatively small-size accelerators. The ERAB assessment of a full-size accelerator concluded that the technology was feasible and held certain safety and environmental advantages over reactor production of tritium. However, these advantages were greatly diminished in ERAB's view because of the problems associated with acquiring and ensuring the large amount of power necessary to operate the accelerator. ERAB did not consider smaller accelerators that could produce 50 percent or 25 percent of the needed tritium and individually use less power. These accelerators could be located in different areas to take advantage of existing surplus power and retain the safety and environmental advantages. In addition, the estimated capital and operating costs initially prepared by DOE/Martin Marietta and presented in the ERAB report were substantially higher than those previously reported by Grumman Aerospace Corporation and LANL and contained in our report.

Recent decreases in projected tritium needs for servicing existing and planned nuclear weapons, and a new target concept for the accelerator technology may provide significant benefits. The projected decrease in the need for tritium could make the small accelerators more attractive because they may be capable of meeting future tritium needs, thus reducing the amount of electric power needed for the process. In addition, the successful development of the helium-3 target could almost eliminate radioactive waste from the tritium production cycle.

While we take no position on constructing an accelerator for the production of tritium, we do believe it is a valid technology that deserves more balanced consideration in DOE's tritium production planning. Currently, the momentum within DOE is focused on building a new production reactor on an urgent schedule. Our work has shown, however, that reduced tritium demand can make accelerators more attractive than shown in the 1990 ERAB report, especially if smaller accelerators are considered. Accordingly, as we pointed out in our February 1991 tritium requirement report, we believe it is important that decisions concerning nuclear materials production take into account all technologies and their potential benefits.

Agency Comments

As previously agreed with your office, we did not obtain written agency comments on a draft of this report. However, we did discuss the facts contained in the report with DOE and LANL officials and made changes where appropriate. Overall, DOE officials had three major concerns related to our work. DOE officials stated that (1) a large cost contingency is justified for an accelerator; (2) we did not consider accelerator production of other isotopes, such as plutonium, needed for defense purposes; and (3) we did not compare technical, schedule, and cost risks of an accelerator against those of reactors.

DOE officials believe that a large cost contingency is appropriate for an accelerator because the continuous operation of an accelerator system in a production mode is a challenging undertaking and the proposed schedule for developing such a system is very aggressive. We believe some contingency is appropriate to cover development risks such as those mentioned by DOE officials. However, we believe it is important to recognize that the accelerator has certain unique features, such as the replicative nature of most of its components, many of which have been used in other accelerators and assigned a low risk by ERAB. In our view, such features tend to lower risk and can affect the cost contingency assigned to the accelerator.

DOE officials pointed out that we did not consider accelerator production of other isotopes, mainly plutonium, during our review. DOE believes this is an important requirement for any new production technology and states that reactors are capable of producing these isotopes. While the focus of our review was on the ERAB assessment, which did not consider plutonium production using an accelerator, we asked LANL officials to provide us with information on the accelerator production of necessary plutonium isotopes. These officials told us that the plutonium isotopes, using their new target concept, can be produced in an accelerator with safety advantages when compared with reactor production. However, we did not evaluate plutonium production in this report because ERAB did not assess it in its 1990 report. In our view, plutonium isotope production and the need for such plutonium should be assessed in any further consideration by DOE of an accelerator for nuclear material production.

Finally, concerning DOE's overall comment about comparing accelerators with reactors, our review focused on the 1990 ERAB assessment, which did not make such a comparison. However, we are aware of the environmental, safety, cost and schedule, and technical issues associated with both technologies. These issues have been reported to DOE by ERAB in separate assessments made of the reactor and accelerator technologies. In addition, our February 1991 tritium requirement report stated that a more detailed comparative assessment should be done by DOE as it formulates plans to replace existing nuclear material production capacity. While we do not take a position on one technology over another, we do believe they all should be considered in a balanced way in DOE's planning process. Nuclear material production is critical to our national defense, and all potential technologies should be completely assessed in determining what technology best meets our national defense needs in an environmentally sound and safe manner.

The information in this report is based on a detailed analysis of ERAB's assessment and resulting report. During our review we interviewed several ERAB members, DOE and Martin Marietta officials, and LANL officials responsible for the accelerator conceptual design. We also reviewed documents and interviewed officials at the Bonneville Power Administration and the Tennessee Valley Authority to determine projected electric power costs in the respective regions. We were assisted in these activities by Dr. George Hinman, a nuclear physicist at Washington State University. Our work was performed between February 1990 and July 1991 in accordance with generally accepted government auditing standards.

Unless you publicly announce its contents earlier, we plan no further distribution of this report from 30 days from the date of this letter. At that time, we will send copies to appropriate congressional committees; the Secretary of Energy; and the Director, Office of Management and Budget. We will also make copies available to others upon request. If you have any questions concerning this report, please call me at (202) 275-1441. Other major contributors to this report are listed in appendix IV.

Sincerely yours,



Victor S. Rezendes
Director, Energy Issues

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Abbreviations

DOE	Department of Energy
ERAB	Energy Research Advisory Board
GAO	General Accounting Office
Kwh	Kilowatt hours
LANL	Los Alamos National Laboratory

Contents

Background

The Department of Energy (DOE) is responsible for supplying nuclear weapons material for U.S. defense purposes. Tritium is an important material used in nuclear weapons. However, it decays rapidly and has to be replenished periodically in the weapons. Tritium has historically been produced by reactors located at DOE's Savannah River Site near Aiken, South Carolina. However, because of age and safety problems, these reactors have been shut down since 1988.

In August 1988, DOE issued a report to the Congress recommending construction of two new production reactors, one a heavy-water reactor at DOE's Savannah River Site and a gas-cooled reactor at DOE's Idaho National Engineering Laboratory near Idaho Falls, Idaho. DOE has pursued the two-reactor strategy and in 1990 initiated preliminary design for both reactors. However, in February 1991 DOE announced it would build only one reactor initially and delay construction of the other one indefinitely. The selection of the reactor technology and locations is scheduled for December 1991.

The two-reactor strategy was deemed appropriate because of the large amount of tritium required in 1988. The heavy-water reactor is being designed to produce 100 percent of the 1988 tritium need, and the gas-cooled reactor to produce 50 percent of the need. The basis for the recommended two-reactor strategy was a report prepared by DOE's Energy Research Advisory Board (ERAB),¹ that assessed several reactor technologies. The ERAB assessment included a brief look at an accelerator as a possible technology for tritium production and concluded that the technology was not developed enough for further consideration.

In March 1989, Los Alamos National Laboratory (LANL) and Brookhaven National Laboratory issued a report concluding that accelerator production of tritium was technically feasible and had cost and schedule advantages over a reactor. In August 1989, DOE requested ERAB to evaluate accelerator production of tritium using, to the extent possible, the same criteria used for the reactor technologies. ERAB issued its report in February 1990,² which concluded that accelerator production of tritium was technically sound. In addition, the report contained the following conclusions.

¹ERAB was an independent advisory board appointed by the Secretary of Energy to provide input to DOE on technical issues such as technologies for tritium production.

²Accelerator Production of Tritium (APT), A Report of the Energy Research Advisory Board to the U.S. Department of Energy, Feb. 1990.

- Accelerator production of tritium offers significant safety and environmental advantages over reactors because of the lack of nuclear criticality (safety) and radioactive waste (environment).
- A strong program of research and development, along with engineering demonstration, is required before the proposed accelerator can be designed and constructed.
- The major risk associated with accelerator production of tritium is the proposed lead/lithium target, which is only a concept requiring an extensive experimental and design effort.
- A major disadvantage is the acquisition of the large amount of electric power (900 megawatts) needed to power a full-size accelerator.
- The estimated capital costs were approximately \$5.3 billion, and the estimated operating costs were \$800 million annually.

In addition, the ERAB's Technical Assessment Working Group recommended that a decision to make an investment to build the first section of the accelerator be made as soon as possible. According to this working group, this section would take about 4 years and \$200 million for engineering, fabrication, and construction. The ERAB's working group further stated that the satisfactory operation of the first section would provide the greatest degree of confidence in the eventual success of the accelerator technology. In addition, the working group's report stated, "We know no other system proposed for PT [production of tritium] that can have this type of verification of ultimate objectives this early in the program." The recommendation, however, was not contained in the ERAB report to DOE.

In February 1990, we issued a report on accelerator production of tritium.³ Our report generally agreed with the ERAB report except for the estimated cost. The capital and operating costs in our report were substantially lower than those presented in ERAB's report. In addition, we provided information on downsized accelerators that would lessen the impact on electric power acquisition. For example, an accelerator capable of producing 25 percent of the tritium need would use about 260 megawatts of electricity. Appendix II contains information on ERAB's criteria, and appendix III discusses the cost estimates presented in the ERAB report.

³Nuclear Science: The Feasibility of Using a Particle Accelerator to Produce Tritium (GAO/RCED-90-73BR, Feb. 2, 1990).

ERAB's Assessment Limited

In August 1989, the Secretary of Energy requested ERAB to assess the status of accelerator technology for the production of tritium. The request directed ERAB to use the same criteria, whenever possible, that were used in assessing reactor technologies for tritium production. One of the main criteria required that the accelerator technology have the capability to produce, annually, 100 percent of the tritium need as established by DOE in 1988. This has commonly been referred to as the goal amount. The accelerator technology was assessed against this criterion, although DOE had already recommended construction of a down-sized reactor capable of producing only 50 percent of the goal amount. By using the criterion (goal amount), ERAB's assessment was limited to an accelerator that required a large amount of electric power to operate. The estimated power necessary to operate such an accelerator is 900 megawatts (ERAB's estimate). This amount of power is approximately the amount produced by a large commercial power plant.

There are basically two major disadvantages associated with acquisition of large amounts of power. First, if a new power-generating facility is required to supply power, then the environmental consequences of the new generating facility would be attributed to the accelerator. Thus, many of the safety and environmental advantages associated with the accelerator would be lost. Second, the large amount of power would require special contracting arrangements with a utility. In other words, before a utility would begin to construct a new generating facility, it would want a long-term contract for purchase of the power. This would affect the schedule of the accelerator, because a generating facility takes 10 to 15 years to construct, and a contract probably would not be negotiated until the accelerator was proven. ERAB pointed out both disadvantages in its report.

The ERAB report did not discuss downsized accelerators that would produce less than the goal amount and provide flexibility in power acquisition. However, ERAB did note that

"Any reduction of the goal quantity of tritium would reduce the use and cost of electricity proportionately. Annual operating costs would decrease significantly if the goal quantity were reduced to a level where off-peak power could be used for all operations."

ERAB also briefly mentioned the concept of duality, or having two accelerators at different locations. However, ERAB dismissed the idea by stating that duality was not necessary for accelerator production of tritium because DOE's plans to proceed with reactor production of tritium

already provided diversity of technologies and sites. There was no other discussion of the advantages of downsized accelerators in different locations.

Cost Estimates Contained in the ERAB Report

The accelerator cost estimates contained in ERAB's February 1990 report were initially developed by DOE and its contractor, Martin Marietta. These estimates were substantially higher than previous estimates by Grumman Aerospace Corporation, LANL,¹ and those presented in our February 1990 report. The DOE/Martin Marietta estimates were a result of increases made to earlier estimates prepared by LANL and Grumman Aerospace Corporation. ERAB slightly modified the DOE/Martin Marietta estimates before publishing them in its final report.

Capital Costs

The capital cost estimate initially developed by DOE/Martin Marietta and presented in ERAB's 1990 report was \$5.3 billion. This was substantially higher than previous estimates. The major increase from previous estimates was a result of large contingency costs assigned to the base cost by DOE/Martin Marietta because of technology and scheduling risk. Contingency cost accounted for \$1.1 billion, or 30 percent, of the estimated capital cost.

Much of the accelerator components and systems are known technologies for which there is a low risk for successful application. For example, the "radio-frequency system" and the "coupled cavity linac," which account for about 72 percent of the accelerator structure cost, are proven technologies that have little risk after engineering design is complete.² In addition, these are replicated components that make up 2,063 meters of the 2,093 meter-long accelerator. For example, there are an estimated 450 radio-frequency power systems that supply power to the particles as they travel the 2,063 meters down the accelerator. Each system is estimated by Grumman Aerospace Corporation to cost \$1.6 million, or a total of about \$739 million. According to a vendor that submitted the estimate to Grumman Aerospace Corporation, some modifications would have to be made to obtain the desired frequency and to improve the system's efficiency.

Another example is the coupled cavity linac sections that are used in several accelerators now in operation. Again, these are replicated components that make up the 2,063-meter structure. They are placed end to

¹These estimates were contained in a joint report by LANL and Brookhaven National Laboratory entitled Accelerator Production of Tritium (APT), Mar. 1989.

²The radio-frequency system inputs the electric power and supplies the desired frequency to accelerate the particle beam. The coupled cavity linac is a pipe-like copper structure through which the nuclear particles are accelerated and supplied with energy (electric power).

end and form a continuous pipe-like structure through which the particles are accelerated and guided. The total estimated cost of this component is \$844 million. However, once the first short section is engineered and proven, the remaining sections are basically replications.

In the ERAB report, a 30-percent contingency, or \$1.1 billion, was assigned to the estimated capital cost to compensate for technical and schedule uncertainties. This high contingency amount does not appear to reflect the technological status of individual components, nor does it appear to reflect the replicated nature of components that comprise the majority of the cost. In our view, a \$1.1-billion contingency may not be appropriate.

During our review, we obtained a report prepared by ERAB's Technology Assessment Working Group that categorized the risk associated with accelerator component development. Both the coupled cavity linac and the radio-frequency system were termed as low risk. In addition, this group noted that both components have had relevant experience at existing accelerators.

Operating Costs

Operating costs are annual reoccurring costs associated with operating a facility. These costs are important when comparing various alternatives because they make up a very large percentage of life-cycle costs, or the total cost of a project over its expected life—40 years for a tritium production facility. Thus, life-cycle costs include capital cost and total annual operating costs for 40 years.

In March 1989 LANL estimated annual operating costs at \$281 million a year, or a total of about \$11.2 billion over a 40-year period.³ This estimate was contained in our February 1990 report on accelerators. In November 1989 DOE/Martin Marietta estimated the annual operating costs at \$424 million, or a total of about \$17 billion. The final estimated annual operating cost contained in ERAB's February 1990 report was \$800 million or a total of \$32 billion. This was almost three times the initial estimate LANL made in March 1989. The major increases were in the cost of electricity and the addition of \$140 million annually for "capital upgrades." These alone resulted in increases of about \$308 million annually.

³Although the operating cost estimates are presented in constant 1989 dollars to account for expected inflation, they have not been converted into present values that would also account for the time value of money. Measured in present value terms, the estimates would be lower.

Electric Power Costs

The cost estimates for purchasing electric power to run the accelerator contained in the ERAB report were based on an analysis by DOE/Martin Marietta of two regional electric power markets as possible sites. As a result, the ERAB report estimated that power costs in the Pacific Northwest and in the Southeast would exceed 50 mills/kilowatt hours (Kwh) in the year 2010. The specific power cost presented in the ERAB report was 56 mills/Kwh. This was also the DOE/Martin Marietta estimated power cost for the Pacific Northwest. In both locations it was assumed that DOE would have to bear the total marginal cost of constructing and operating a coal-fired plant.

In practice, regional utilities generally average the cost of new resources (such as a coal plant) into their overall rate base for a large user such as DOE. This is particularly true in the Pacific Northwest, which would combine a coal plant (the most expensive new source identified there) with much cheaper hydroelectric power. In this respect, the Bonneville Power Administration projects a "new resource customer" rate of 33.8 mills/Kwh for firm electric power in the Pacific Northwest for the year 2010. This amount is almost equal to the amount used in the March 1989 LANL report and contained in our February 1990 report.

Capital Upgrades

Finally, during our review, we noted that the ERAB final report included in its accelerator cost assessment an annual cost of \$140 million for capital upgrades. In our view, this cost is difficult to justify. We could not identify any accelerator components or systems that would require upgrades at this cost on an annual basis. The only major or costly components that require replacement on a periodic basis are the klystron tubes. However, these were included as a separate line item in the estimated operating costs.

We asked officials at LANL responsible for operating the Los Alamos Meson Physics Facility, a proton accelerator, if they had incurred any expenditure for capital upgrades, or if they could identify any for an accelerator. They said that the only expenditures an accelerator might require would be general maintenance-type expenditures. According to information acquired from LANL, the entire operating cost for its accelerator facility in 1989 was \$17.8 million. We also asked DOE/Martin Marietta officials, who initially developed the cost estimates, to identify what capital upgrades would be necessary on an annual basis or during the accelerator's life. These officials could not identify any accelerator upgrades and said the cost was added because a similar cost was added to the reactor cost estimates.

Major Contributors to This Report

Resources,
Community, and
Economic
Development Division,
Washington, D.C.

Judy A. England-Joseph, Associate Director, Energy Issues
William F. Fenzel, Assistant Director
W. David Brooks, Evaluator-in-Charge